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VERTICAL CLOUD STRUCTURE MODELS FOR THE NTRZ EQZ, SEB AND STRZ OF JUPITER

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Latitude-dependent models of the vertically inhomogeneous Jovian cloud structure are presented. The models assume an atmospheric composition with $[CH_4]/[H_2] = 2.0 \times 10^{-3}$, $[He]/[H_2] = 0.11$ and $[NH_3]/[H_2] = 2.0 \times 10^{-4}$ consistent with the Voyager IRIS measurements and employ refractive indices appropriate for ammonia ice particles and a photochemical stratospheric aerosol layer. The free parameters of the models are determined by fitting the results of multiple scattering calculations to the near-infrared center and limb spectra of Clark and McCord (1979, Icarus *40, 180-188) and the center-to-limb 6190, 6350, 7250, 7500, 8900 and 9500 Å photometric measurements of West (1979,* Icarus *38, 12-33). The resulting synthetic center-to-limb profiles are in excellent agreement with the observations. Of the regions studied the tropical zones are the most similar, with the observed differences explained by variations in the vertical extent of the cloudy layers. The Equatorial Zone is a unique region with denser NH_3 clouds than either of the tropical zones. At visible and near-infrared wavelengths the belt-zone contrasts can be explained by opacity differences. The optical depth of the stratospheric aerosol layer is larger in a belt, while the tropospheric clouds are deeper and thinner.*

We began this modeling of the vertical cloud structure of the Jovian atmosphere by using the center and limb near-infrared spectra of Clark and McCord (1979). The spectral range of the data is 0.65-2.5 microns. Each spectrum consists of data from 120 individual spectral channels. Thus 240 individual data points were originally considered. The lack of laboratory methane data precludes the modeling of the entire spectral region, therefore roughly only half of the data can be modeled. One of the other problems encountered in working with the Clark and McCord spectra are the uncertainties in the viewing geometry. For this reason our model is also required to reproduce the spatially resolved CCD photometry of West (1979) for which the viewing geometry is known. Of particular interest are the individual belts and zones which were unresolved but contained in the larger field of view of the Clark and McCord measurements.

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Our modeling approach is straightforward; we begin by assuming an atmospheric composition consistent with the Voyager analyses of Kunde *et al.* (1982). Mie theory is used to determine the scattering properties (e.g., single scattering albedo and asymmetry parameter) of the various cloud layers. The cloud layers are modeled as diffuse clouds. As in the real atmosphere, gas absorption occurs within both the clear gas layers and the individual cloud layers in this model. The optical properties for the ammonia ice are taken from Martonchik *et al.* (1984). Starting with the wavelength where the atmospheric gas opacities are the largest, 2.3 μm, and proceeding to the shorter wavelengths (smaller atmospheric opacities) - we begin by trying to fit the data with simple atmospheric models. First a reflecting layer model is used to infer the cloud top pressure and then a homogeneous cloud model is used to determine the vertical extent of that cloud layer. Where the homogeneous cloud model is no longer able to reproduce the observations, we assume that the atmosphere is no longer homogeneous and add another layer to our model vertical structure. Since both the reflecting layer model and the homogeneous cloud model are unable to reproduce, simultaneously, both the center and limb measurements of Clark and McCord, we were forced to consider, at the outset, a two cloud model. The upper cloud in this model is the stratospheric aerosol layer, while the lower cloud is the tropospheric ammonia cloud layer. The optical properties for the stratospheric aerosol layer are taken from Podolak and Danielson (1977). They found the wavelength dependence of the aerosol extinction to be $\lambda^{-2.5}$. This value is within the range of acceptable values more recently determined by Tomasko.

The vertical cloud structure for the equatorial region of Jupiter that emerges from this investigation is a seven layer model. The seven layers, from top to bottom, are: a clear gas layer; a stratospheric aerosol layer; a second clear gas layer; an ammonia haze; a denser ammonia cloud; a clear gas layer and finally the base cloud layer. This seven layer model was used as the starting point in our investigation into the vertical cloud structure of the tropical zones and equatorial belts using the CCD photometry of Bob West.

Figure 1 shows the model fit to the methane band photometry of the North Tropical Zone, the Equatorial Zone, the South Equatorial Zone and the South Equatorial Belt. The data points plotted are the CCD measurements with their 8% error bars. As can be seen, the model fit is quite good. The wavelength dependence of the optical properties of the stratospheric aerosol layer, taken from Podolak and Danielson, and that of ammonia ice coupled with the *wavelength dependent gas absorptions* due to hydrogen and methane are able to account for the wavelength dependence of the reflected solar radiation measured at these wavelengths. It is thus not necessary, at these wavelengths, to include any extra absorption due to a chromophore. The relatively poorer, though still acceptable, model fit at 7250 Å is most likely due to the presence of larger cloud particles at the base of the ammonia cloud layer. The presence of larger particles near the cloud base would reconcile the differences in the particle sizes inferred from this study and those determined from the analyses of thermal infrared data. The particle sizes which provide the best fit to the data are 0.6 μm for the ammonia haze layer and 0.8 μm for the ammonia cloud layer. These sizes are representative of the particles found in the upper regions of both layers, as these are the regions most sensitive to reflected solar radiation. The stratospheric aerosol layer is found to contain smaller particles;

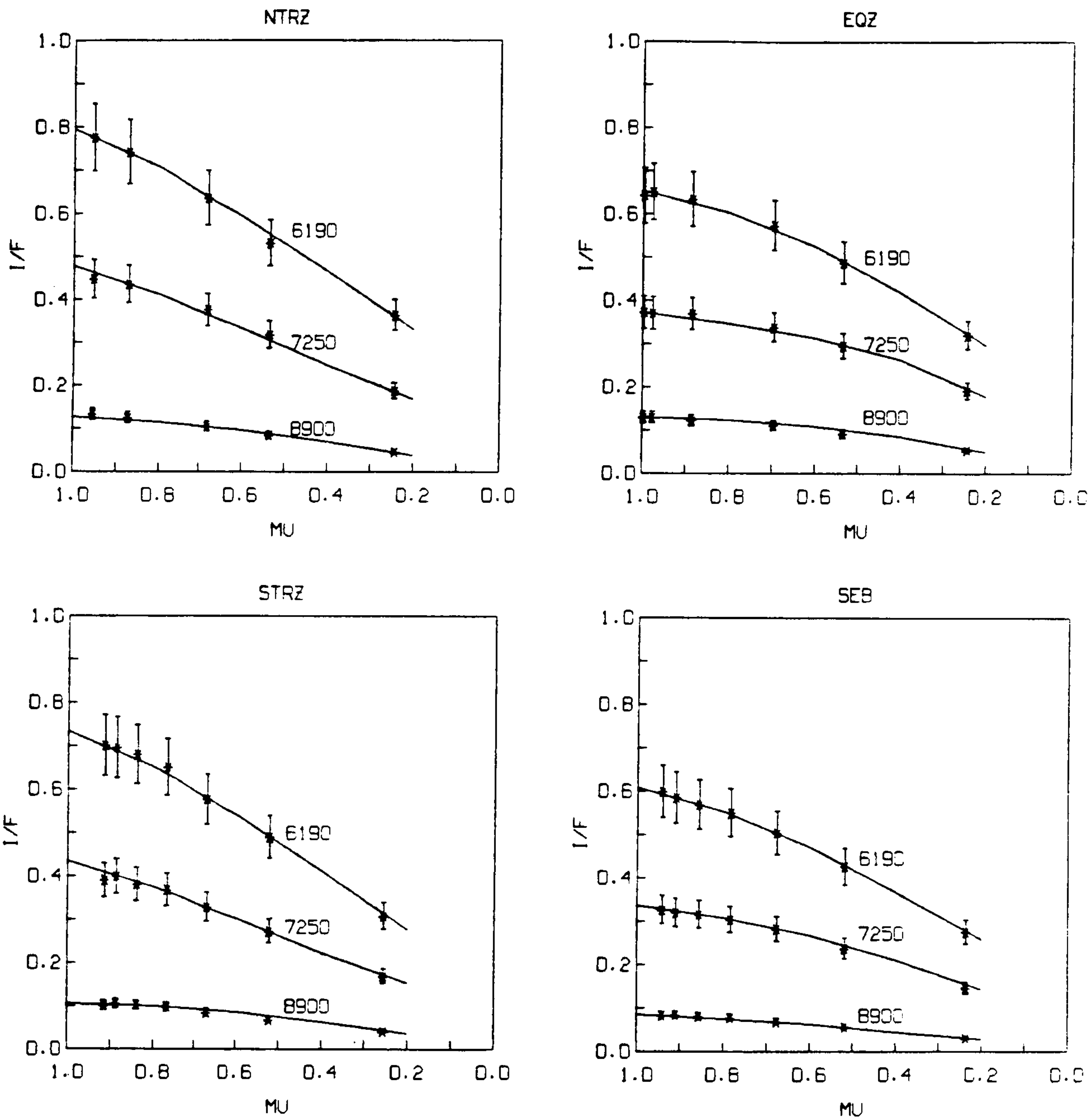

Figure 1. The model fits to the NTrZ, EqZ, STrZ and SEB methane band photometry.

the average particle radius is approximately 0.1 μm. Again this value is within the range of acceptable particle sizes found by Tomasko *et al.* (1986); their preferred particle size is 0.2 with an uncertainty of +0.3/-0.1.

The differences found between the vertical structure of the North Tropical Zone and the South Tropical Zone are found to be due to cloud opacity variations. The optical depth of the ammonia cloud is less in the South Tropical Zone than in the North Tropical Zone. This explains the higher continuum reflectivity found in the NTrZ. The Equatorial Zone is distinct from the other two zones studied here in that the ammonia cloud is optically thicker than that found in either tropical zone. The optical depth due to the ammonia at continuum wavelengths is 2.5 compared with the optical depths of 1.5 and 2.0 found in the North and South Tropical Zones, respectively.

The differences between belts and zones in our analysis are explained by lower cloud top altitudes in belts relative to zones. The top of the ammonia haze layer is at 300 mb in the SEB versus the 200 mb cloud top pressures found for the tropical zones. In addition to the ammonia cloud top altitude variations between belts and zones, there are also differences in the location of the base cloud with latitude. In the SEB the top of the base cloud is encountered at a pressure of 1.8-2.0 bars versus the 1.4-1.6 bar cloud tops found in the zones. We do not, however, find any particle size variations between the base clouds found in belts and those found in zones. This may be due to the fact that the reflected solar radiation modeled here may be more sensitive to certain particle sizes than others. There are some optical depth variations in the base cloud with latitude. These variations may explain some of the variations with latitude found in the 5 μm Voyager IRIS spectra. In particular, the optical depth of the base cloud in the belt is less than that encountered in the zones. This may explain the higher 5 μm emission in belts.

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DR. TOMASKO: What is the opacity of the stratospheric aerosol at continuum wavelengths?

DR. CARLSON: At continuum wavelengths it's tenths.

DR. ALLEN: I wonder whether the spectrum of the chromophores is the single scattering albedo change with wavelength of something on the order of Sato and Hansen. At the wavelength that you're working, the chromophore properties may be the same as the ammonia cloud properties. In fact, you may not be able to distinguish one from the other...

DR. CARLSON: Right--I'm not saying that chromophores are unnecessary at other wavelengths. But I am saying that I do not need extra absorption, in the form of a "chromophore" at these red and near-infrared wavelengths. A chromophore may be required to model the blue portion of the spectrum, but I am not modeling blue data, so I really cannot say. If there is a chromophore, which there most likely is, then to be consistent with the results of this analysis it cannot absorb significantly at wavelengths from 0.6-2.5 μm.

DR. WEST: What is the single scattering albedo of the ammonia particles in those wavelengths?

DR. CARLSON: The single scattering albedo of the ammonia haze layer is adjusted at each wavelength to include the effects of the gas absorption: it is not due to the ammonia haze particles alone. Thus, at 6190 Å the model single scattering albedo is 0.95 while that of ammonia ice alone is 0.997. This is one of the interesting results of this analysis. In comparing the single scattering albedo and the asymmetry parameter of my ammonia haze at 6190 Å with the values determined by Marty Tomasko from the Pioneer data for the stratospheric aerosol layer, I find that these values agree quite nicely. The stratospheric aerosol layer is much darker in my models than that in Marty's models. The single scattering albedo of my stratospheric aerosol layer is 0.64 at 6190 Å.

DR. TOMASKO: I still don't quite understand. You have the haze particles which add some absorbers, and you manage to relate those to some power. But in the ammonia cloud itself, do you have the same kind of material? The ammonia clouds are basically...

DR. CARLSON: The ammonia cloud is modeled as a diffuse cloud. Therefore, in addition to containing ammonia ice particles, the clouds also contain a mixture of methane and hydrogen gas.

DR. TOMASKO: O.K., but in the continuum where the methane doesn't absorb, basically it's 1.0 for the single scattering albedo. I think we had a lot of problems getting the Pioneer data to fit limb darkening if all the absorber is concentrated above, bright clouds beneath. I wonder if you tried to fit your model with the Pioneer data...

DR. CARLSON: No, I have not yet tried to model the Pioneer data.

DR. ROSSOW: Marty, keep in mind that the single scattering albedo is not identically one, but 0.98--that's an important difference.